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APPLICATION OF FAULT CURRENT LIMITERS FOR PROTECTION OF MICRO GRID

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ABSTRACT

Smart grid will integrate modern communication technologies and renewable energy resources into the future power grid, in order to supply more efficient, reliable, resilient and responsive electric power. A superconducting fault current limiter (SFCL) is a device that uses superconductors to instantaneously limit or reduce unanticipated electrical surges that may occur on utility distribution and transmission networks. When an unplanned event, such as lightning or downed power lines, occurs, a large surge of power can be sent through the grid resulting in a fault. Serious faults can generate surge currents more than one hundred times the normal operating currents. These faults can result in damage to expensive grid-connected equipment.

SFCL's eliminate or greatly reduce the financial burden on the utilities by reducing the wear on circuit breakers and protecting other expensive equipment. Utilities can reduce or eliminate the cost of circuit breakers and fuses by installing SFCL. At the same time, these allow utilities to avoid or delay upgrading existing circuit breakers and electrical substations to handle ever higher electrical surges. Fault currents in transformers, for instance, can run 10- 20 times the steady state design current. SFCL can reduce these fault currents to levels not exceeding 3-5 times the steady state current, protecting and extending the life of transformers and associated utility equipment. As for a dispersed energy resource, 10 MVA wind farm was considered for the simulation. Three phase faults have been simulated at different locations in smart grid and the effect of the SFCL and its location on the wind farm fault current was evaluated. Two wind farms were considered and their performance is also evaluated. Consequently, the optimum arrangement of the SFCL location in Smart Grid with renewable resources has been proposed and its remarkable performance has been suggested.

KEYWORDS: Microgrid, Smart Grid, Superconducting Fault Current Limiter

INTRODUCTION

Electric power systems are designed such that the impedances between generation sources and loads are relatively low. This configuration assists in maintenance of a stable, fixed system voltage in which the current fluctuates to accommodate system loads. The primary advantage of this arrangement is that loads are practically independent of each other, which allows the system to operate stably when loads change. However, a significant drawback of the low interconnection impedance is that large fault currents (5 to 20 times nominal) can develop during power system disturbances [1]. In addition, the maximum fault current in a system tends to increase over time for a variety of reasons, including:

- Electric power demand increases (load growth) and subsequent increase in generation.
- Parallel conducting paths are added to accommodate load growth.
- Interconnections within the grid increase.
- Sources of distributed generation are added to an already complex system.

Smart grid is a term used for future power grid which integrates the modern communication technology and renewable energy resources for the 21 st century power grid in order to supply electric power which is cleaner, reliable, resilient and responsive than conventional power systems. In an effort to prevent damage to existing power-system equipment and to reduce customer downtime, protection engineers and utility planners have developed elaborate schemes to detect fault currents and activate isolation devices (circuit breakers) that interrupt the overcurrent sufficiently rapidly to avoid damage to parts of the power grid. While these traditional protection methods are effective, the ever-increasing levels of fault current will soon exceed the interruption capabilities of existing devices.

Shunt reactors (inductors) are used in many cases to decrease fault current [2]. These devices have fixed impedance so they introduce a continuous load, which reduces system efficiency and in some cases can impair system stability [3]. Fault current limiters (FCLs) and fault current controllers (FCCs) with the capability of rapidly increasing their impedance, and thus limiting high fault currents are being developed.

These devices have the promise of controlling fault currents to levels where conventional protection equipment can operate safely [6-7]. A significant advantage of proposed FCL technologies is the ability to remain virtually invisible to the grid under nominal operation, introducing negligible impedance in the power system until a fault event occurs. Ideally, once the limiting action is no longer needed, an FCL quickly returns to its nominal low impedance state. With Superconducting fault current limiters (SFCLs) utilize superconducting materials to limit the current directly or to supply a DC bias current that affects the level of magnetization of a saturable iron core. While many FCL design concepts are being evaluated for commercial use, improvements in superconducting materials over the last 20 years have driven the technology to the forefront [4]. Case in point, the discovery of high-temperature superconductivity (HTS) in 1986 drastically improved the potential for economic operation of many superconducting devices.

FCLAPPLICATIONS IN SMART GRID

A smart grid integrates advanced sensing technologies, control methods and integrated communications into current electricity grid at both transmission and distribution levels. Compared to the Supervisory Control and Data Acquisition (SCADA) systems in conventional electric power systems, a smart grid with a multi-agent system can operates more efficiently and flexibly. FCLs can be controlled via the communication network of multi-agent systems in smart grid, which play a key role in the FCL applications in smart grid and can increase the accuracy and reliability of system protection. A smart transmission grid consists of three interactive, smart components: smart control centers, smart transmission networks and smart substations. Real-time communication networks, the supporting infrastructure of smart grid, offer more computation and more control to achieve more reliable protection. And fault locations can be identified by intelligent electronic devices with smart approaches in transmission line and distribution system in smart grid.

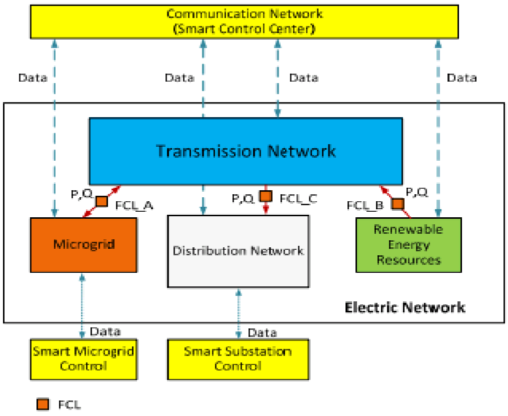


Figure 1: Diagram of a Smart Grid with Electric Network and Communication Network

Figure 1 presents a diagram of a smart grid, which includes an electric network and a communication network. The conventional power network only contains power plants, transmission network and distribution network with master control. In smart grid, microgrids and renewable energy resources distributed throughout the transmission network.

Here we consider distributed generations connected to the transmission network, as shown in Figure 1, not the RERs in distribution network such as rooftop PV. The smart control center communicates with the transmission network, micro grid, RER and distribution network to realize optimal operation and reliable protection of the whole power network. Microgrids and distribution networks have their own smart controls at the substation level. To make full use of these advantages, appropriate FCL devices should be installed at certain nodes in the smart grid. No single FCL category is suitable to handle every node in a power network.

SIMULATION SET-UP

Matlab/Simulink/SimPowerSystem was selected to design and implement the SFCL model. Simulink/Simpower System has number of advantages over its contemporary simulation software (like EMTP, PSPICE) due to its open architecture, a powerful graphical user interface and versatile analysis and graphics tools. Control systems designed in Simulink can be directly integrated with SimPowerSystem models. A complete smart grid power network including generation, transmission, and distribution with an integrated wind farm model was also implemented in it.

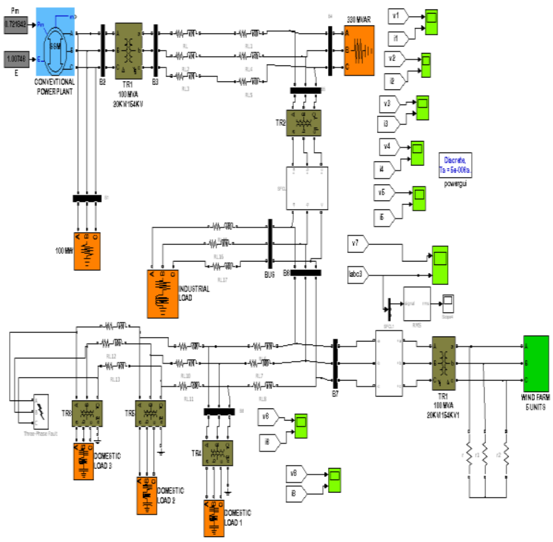


Figure 2: Matlab/Simulink Model

Power System Model

Newly developed micro grid model was designed by integrating a 10 MVA wind farm with the distribution network. The power system is composed of a 100 MVA conventional power plant, composed of 3-phase synchronous machine, connected with 200 km long 154 kV distributed-parameters transmission line through a step-up transformer TR1. At the substation (TR2), voltage is stepped down to 22.9 kV from 154 kV. High power industrial load (6 MW) and low power domestic loads (1 MW each) are being supplied by separate distribution branch networks. The wind farm is directly connected with the branch network (B1) through transformer TR3 and is providing power to the domestic loads. The 10 MVA wind farm is composed of five fixed-speed induction-type wind turbines each having a rating of 2MVA. At the time of fault, the domestic load is being provided with 3 MVA out of which 2.7 MVA is being provided by the wind farm. Four prospective locations for SFCL installation are marked as Location 1 (Substation), Location 2 (Branch Network), Locations 3 (Wind farm integration point with the grid) and Location 4 (Wind Farm). Generally, conventional fault current protection devices are located in Location 1 and Location 2. The output current of wind farm (the output of TR3 in Figure 2 for various SFCL locations have been measured and analyzed in Section III for determining the optimum location of SFCL in a micro grid.

Resistive SFCL Model

The three phase resistive type SFCL was modeled considering four fundamental parameters of a resistive type SFCL [9]. These parameters and their selected values are: 1) transition or response time=2msec, 2) minimum impedance=0.01ohms and maximum impedance=20ohms, 3) triggering current=550A and 4) recovery time=10msec. Its working voltage is 22.9 kV.

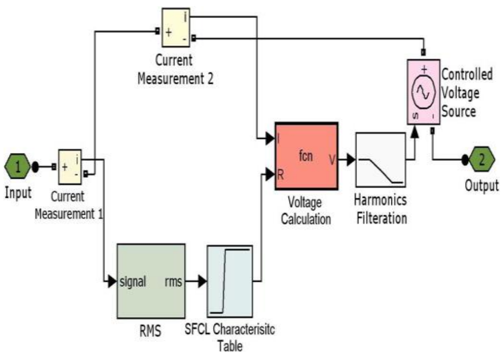


Figure 3: Single Phase SFCL Model Developed in Simulink/Simpowersystem

Figure 3 shows the SFCL model developed in Simulink/Sim- PowerSystem. The SFCL model works as follows. First, SFCL model calculates the RMS value of the passing current and then compares it with the characteristic table. Second, if a passing current is larger than the triggering current level, SFCL's resistance increases to maximum impedance level in a pre-defined response time. Finally, when the current level falls below the triggering current level the system waits until the recovery time and then goes into normal state. SFCL has been located at substation (Location 1) and for a distribution grid fault (Fault 1), various SFCL impedance values versus its fault current reduction operation has been plotted. Maximum fault current (No SFCL case) is 7500 A at 22.9 kV for this arrangement.

SIMULATION RESULTS

Three scenarios of SFCL's possible locations were analyzed for four different fault occurring points and no fault in the power system depicted in Figure 2. First, we assumed that single SFCL was located at Location 1 (Substation).

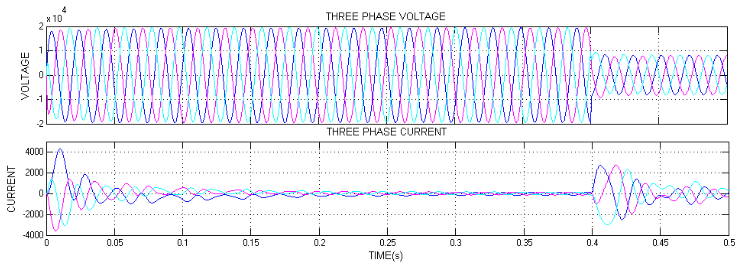
Second, single SFCL was located at Location 2 (Branch Network). Third, single SFCL was located at Location 3 (Wind farm integration point with the grid).

Fault in the Distribution Grid (Fault 1)

In the case of SFCL located at Location 1 (Substation) or Location 2 (Branch Network), fault current contribution from the wind farm was increased and the magnitude of fault current is higher than ‘No FCL’ situation. These critical observations imply that the installation of SFCL in Location 1 and Location 2, instead of reducing, has increased the DG fault current. This sudden increase of fault current from the wind farm is caused by the abrupt change of power system’s impedance. The SFCL at these locations (Location 1 or Location 2) entered into current limiting mode and reduced fault current coming from the conventional power plant due to rapid increase in its resistance. Therefore, wind farm which is the other power source and also closer to the Fault 1 is now forced to supply larger fault current to fault point (Fault 1).

In the case when SFCL is installed at the integration point of wind farm with the grid, marked as Location 3 in Figure 3, the wind farm fault current has been successfully reduced. SFCL gives 68% reduction of fault current from wind farm and also reduce the fault current coming from conventional power plant because SFCL is located in the direct path of any fault current flowing towards Fault 1.

With dual SFCL installed at Location 1 and Location 4, 45% reduction in fault current is also observed. However, even though two SFCLs were installed, wind farm fault current reduction is lower than what was achieved by the single SFCL installed at Location 3. From the simulation results, it was known that the installation of two SFCLs (Location 1 and Location 4) is economically and technically not feasible.



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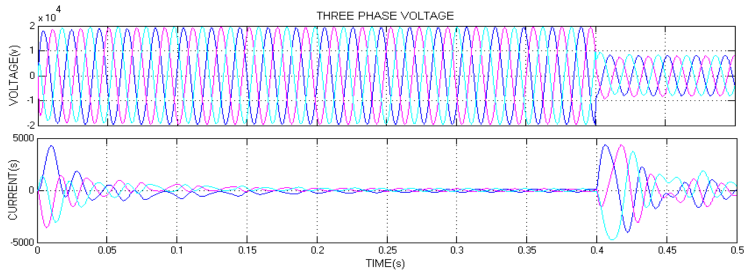

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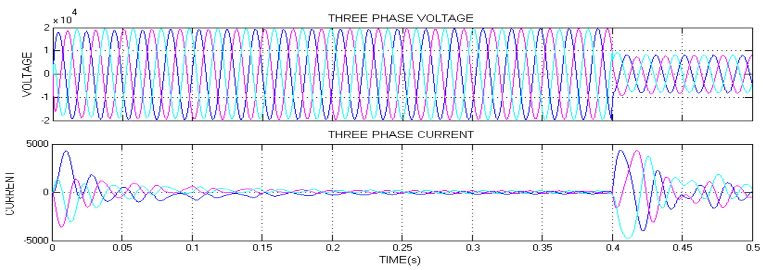

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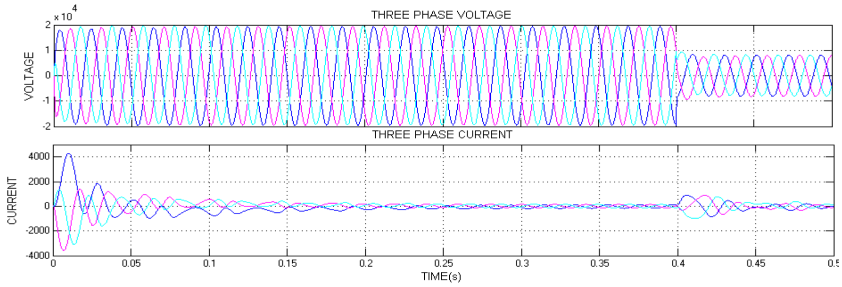

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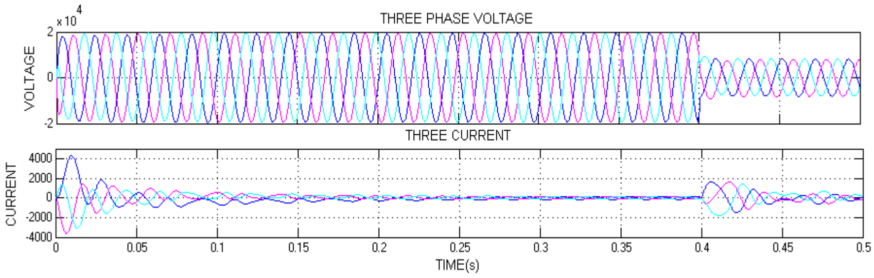

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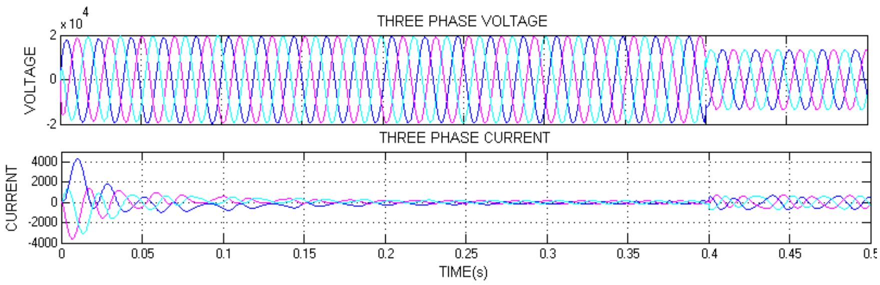
Figure 4: Five Different Fault Conditions Considered at Location 1 (a) Without any Fault, (b) Fault at Location 1, (c) Fault at Location 2, (d) Fault at Location 3, (e) Fault at Location 4

Fault in Customer Grid (Fault 2)

Figure 6 shows a comparison between fault current from the wind farm (measured at output of TR3 in Figure 2 for different SFCL locations in the case when a three-phase-to-ground fault was initiated in the customer grid (Fault 2 in Figure 2). Fault 2 is comparatively a small fault as it occurred in low voltage customer side distribution network. The results obtained are similar to what were observed in the case of distribution grid (Fault 1) as explained in Section III-A.

Once again the best results are obtained when a single SFCL is located at Location 3, which is the integration point of the wind farm with the distribution grid.



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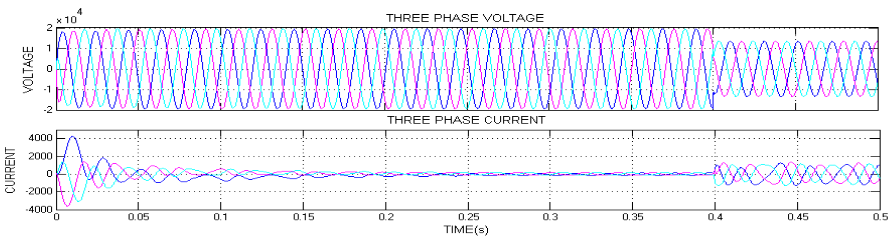

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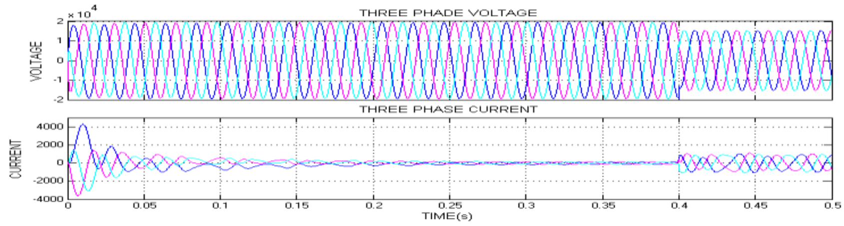

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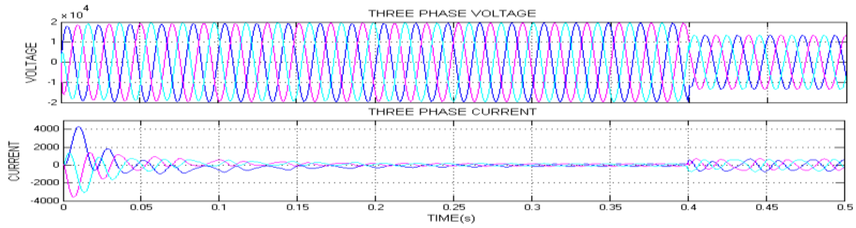

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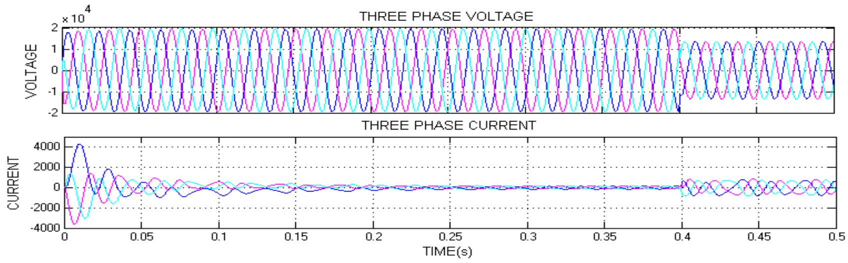

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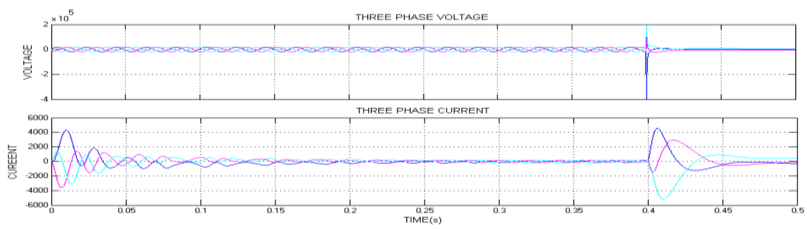
Figure 5: Five Different Fault Conditions Considered at Location 1 (a) Without any Fault, (b) Fault at Location 1, (c) Fault at Location 2, (d) Fault at Location 3, (e) Fault at Location 4

Fault in Transmission Line (F3)

The Fault 3 in Figure 2 indicates the rarely occurring transmission line fault which results in very large fault currents. Figure 7 shows a comparison between fault current from the wind farm (measured at output of TR3 in Figure 2) for different SFCL locations in the case when a three-phase-to-ground fault was initiated in the transmission line (Fault 3 in Figure 2).

When a fault in transmission line occurs, fault current from the conventional power plant as well as the wind farm would flow towards fault point. In case of wind farm, fault current would flow in reverse direction through the substation and into the transmission line to fault point. Thus, on the contrary to the previous results obtained in Sections III-A and III-B, SFCL positioned at Location 1(Substation) or Location 2 (Branch Network) reduces the wind farm fault current. This result comes from the fact that SFCL is installed directly in the path of reverse current being generated by the wind farm towards fault point.



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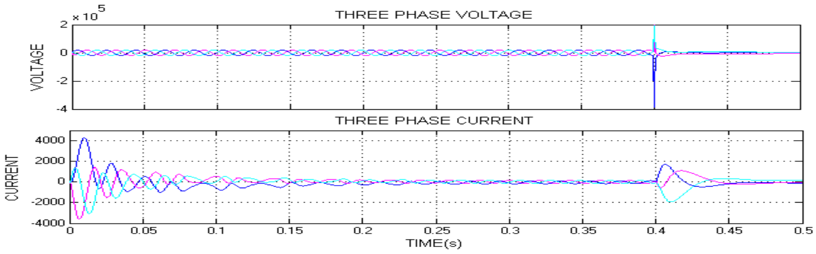

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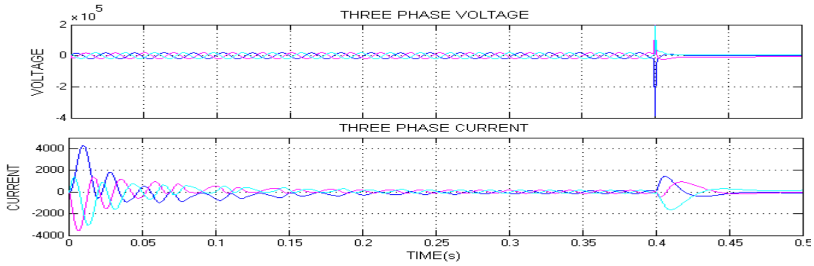

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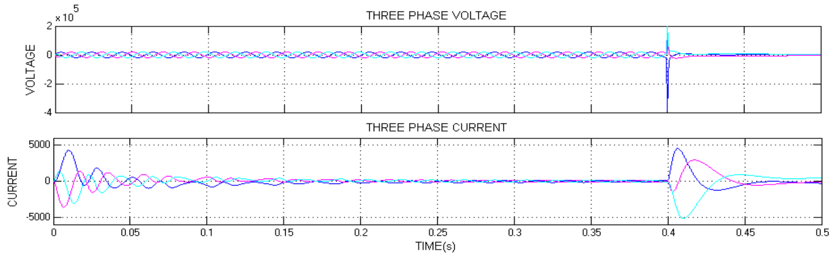

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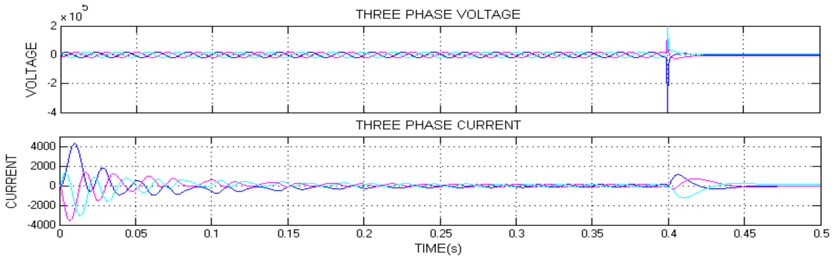

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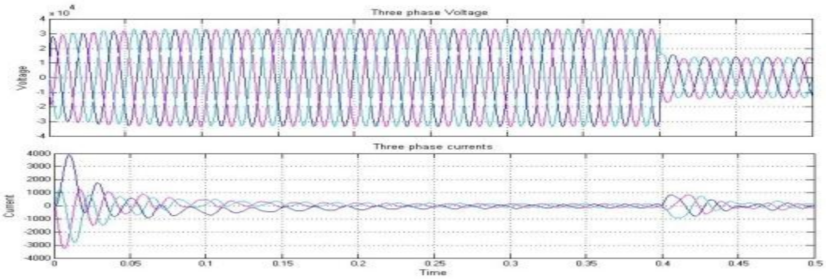
Figure 6: Five Different Fault Conditions Considered at Location 1 (a) Without any Fault, (b) Fault at Location 1, (c) Fault at Location 2, (d) Fault at Location 3, (e) Fault at Location 4

The majority of faults in a power system might occur in the distribution grid and the SFCL designed to protect micro-grid should not be expected to cater for the transmission line faults (Fault 3). An important aspect to be noted here is that wind farms on distribution side can contribute fault currents to transmission line faults and this phenomenon must be considered while designing the protection schemes for the smart grid. When the SFCL was strategically located at the point of integration of the wind farm with the grid (Location 3), the highest fault current reduction was achieved. The performance of SFCL at this location was even better than dual SFCL located at Location 1 and Location 4 at a time. Thus, multiple SFCLs in a micro grid are not only costly but also less efficient than strategically located single SFCL. Moreover, at Location 3, fault current coming from the conventional power plant was also successfully limited.

Further this is extended by adding another two wind farms to the existing one. Once again the process is repeated

and the location of SFCL is analyzed. The analysis is carried out at only fault F1 condition. Here also the fault is created at 0.4s of run time. The analysis concludes that SFCL works effectively when placed at location 3 in three wind farm systems.



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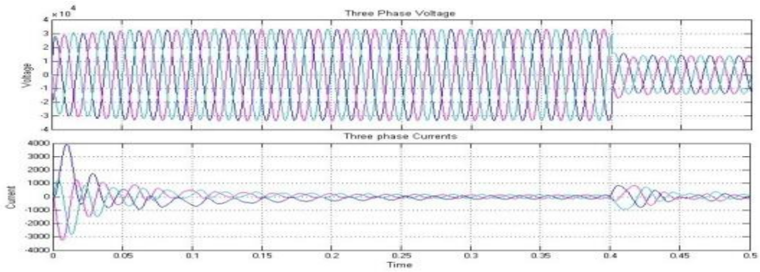

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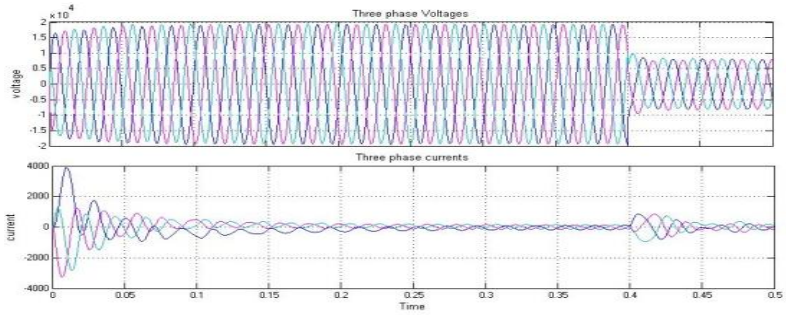

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Figure 7: (A), (B), (C). Fault Currents and Voltage Wave Forms at Different Locations in the System Containing Three Wind Farms

CONCLUSIONS

This paper presented an analysis for possible positioning the SFCL in rapidly changing modern power grid. A complete power system along with three micro grids cascaded to the grid was modeled and transient analysis for three-phase-to-ground faults at different locations of the grid were performed with SFCL installed at key locations of the grid. It has been observed that SFCL should not be installed directly at the substation or the branch network feeder. This placement of SFCL results in abnormal fault current contribution from the wind farm. Also multiple SFCLs in micro grid are inefficient both in performance and cost. The strategic location of SFCL in a power grid which limits all fault currents and has no negative effect on the DG source is the point of integration of the wind farm with the power grid.

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